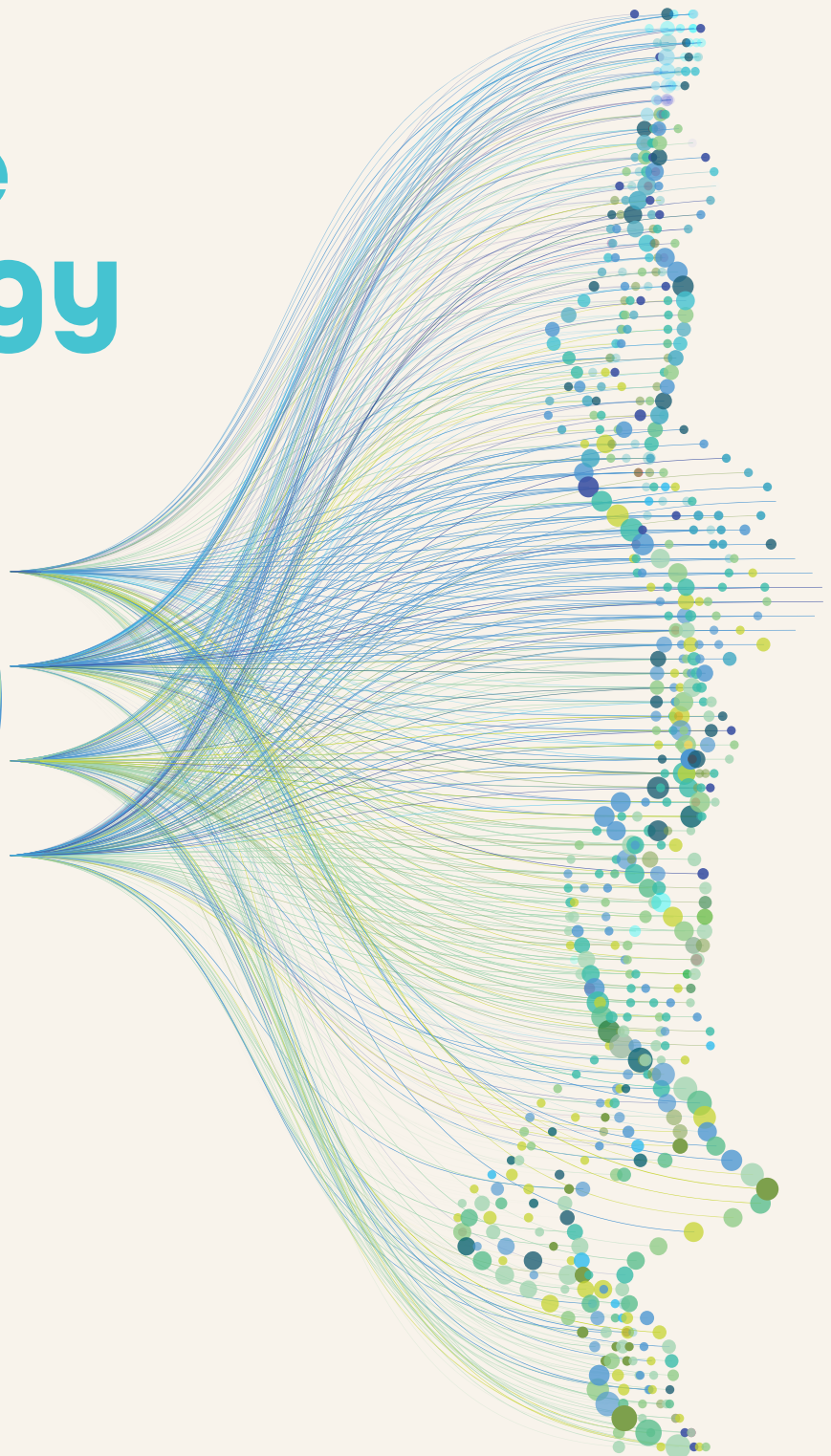# Earth Science Technology Office

2020 Annual Report

Executive Summary

As you'll read in the pages that follow, 2020 was another full and productive year for technology development at the NASA Earth Science Technology Office (ESTO), with numerous successes advancing new technologies for Earth science as well as the competitive selection of new projects, even with the challenges presented by COVID-19. This was the first time that our Earth Science Technology Forum was held virtually due to the COVID-19 restrictions, and we were pleased to have the new Director for Earth Science, Dr. Karen St. Germain, provide the opening address.

In fiscal year 2020 (FY20), ESTO continued to build upon its 20-year heritage of technology development. This year, 55% of active ESTO technology projects advanced at least one Technology Readiness Level, and as many as 24 active and completed projects were transitioned to follow-on development efforts or infused into Earth observing missions, operations, or commercial applications. We are particularly proud to report that at least 130 students – high school through PhD – were directly involved in ESTO-funded projects this year.

In January 2018, the National Research Council (NRC) released the second decadal survey for Earth science: Thriving on Our Changing Planet: A Decadal Strategy for Earth Observation from Space. While many technology investments are already underway to directly support all of the recommended measurements, ESTO has initiated a new program – Decadal Survey Incubation (DSI) – to fund projects that accelerate capabilities in two targeted observable areas: the Planetary Boundary Layer (PBL) and Surface Topography & Vegetation (ST&V). A competitive ROSES-21 solicitation for these observable areas is expected in FY21.

In July 2020, ESTO selected 6 new projects through a competitive solicitation in the Sustainable Land Imaging-Technology (SLI-T) program, and additional awards are expected in late CY2020 from an Advanced Component Technologies (ACT) ROSES-20 solicitation. We welcome this new cohort of technologists and look forward to the contributions they will make, ensuring a bright future for further enabling Earth system science.

Pamela S. Millar
Program Director

Robert A. Bauer
Deputy Program Director

A Northrop Grumman Antares rocket carrying a Cygnus resupply spacecraft launched from NASA's Wallops Flight Facility Saturday, November 2, 2019, in Virginia with the ESTO HARP CubeSat aboard. Read more about this project on page 29. Credit: Bill Ingalls/NASA

About ESTO

140 Projects Active in FY20

31 Projects Added

34 Projects Completed

As the technology development function within NASA's Earth Science Division, the Earth Science Technology Office performs strategic planning and manages the development of a broad range of nascent technologies for future science measurements. ESTO employs an open, flexible, science-driven strategy and relies on competition and peer review to select the best cutting-edge technologies, from advanced sensors aboard miniature satellites to software tools that plan new observations and harmonize, fuze, and analyze large datasets from various sources.

Our approach to Technology Development:

Strategy: Engage with the Earth science community to plan investments through careful analyses of science requirements

Selection: Fund technology development through periodic, competitive solicitations and partnership opportunities

Management: Review and advise funded technology projects on progress and performance

Infusion: Encourage and facilitate the use of mature technologies in science measurements

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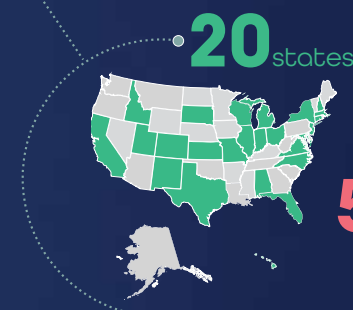**55** unique principal investigator organizations

20 states

593 co-investigators

119 unique co-i organizations

27 states
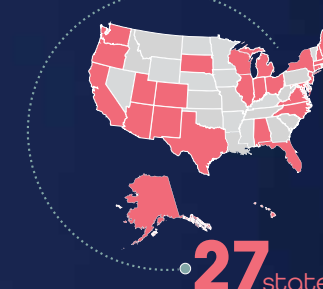
130 students

44 universities

2 cubesats launched

8 projects airborne tested
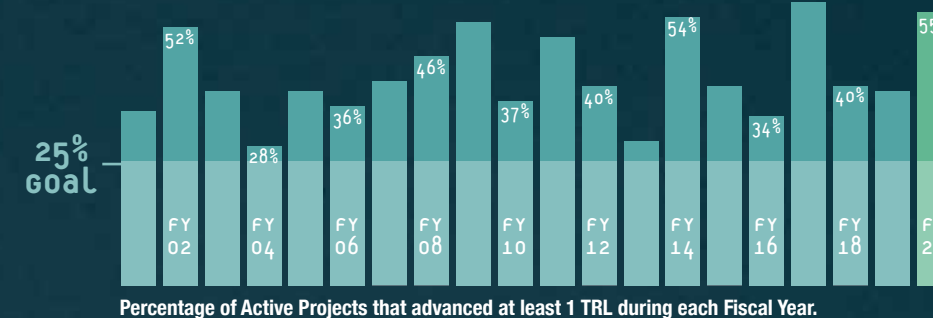
23 journal articles

3 patents

380 Conference Publications (all-time for FY20 projects)

Metrics 2020

With 976 completed technology investments and a portfolio during FY20 (October 1, 2019, through September 30, 2020) of 140 active projects, ESTO drives innovation, enables future Earth science measurements, and strengthens NASA's reputation for developing and advancing leading-edge technologies. To clarify ESTO's FY20 achievements, what follows are the year's results tied to ESTO's performance metrics.

GOAL 1
Annually advance 25% of currently funded technology projects at least one Technology Readiness Level (TRL).

25% goal

52% 28% 36% 46% 37% 40% 54% 34% 40% 55%

FY 02 FY 04 FY 06 FY 08 FY 10 FY 12 FY 14 FY 16 FY 18 FY 20

Percentage of Active Projects that advanced at least 1 TRL during each Fiscal Year.

FY20 Result
55% of ESTO technology projects funded during FY20 advanced one or more TRLs over the course of the fiscal year. Twelve of these projects advanced more than one TRL. Although the percentage of TRL advancements tends to be higher in years with large numbers of completing projects, ESTO has consistently met or exceeded this metric in every fiscal year since inception. The average annual TRL advancement for all years going back to 1999 is 41%.

GOAL 2
Mature at least three technologies to the point where they can be demonstrated in space or in a relevant operational environment.

FY20 Result
In this fiscal year, at least five ESTO projects achieved infusion into science measurements, airborne campaigns, data systems, or follow-on development activities. Three notable examples follow.

GOAL 2 Project Highlight

SoilSCAPE

An in situ SoilSCAPE (Soil Moisture Sensing Controller And oPtimal Estimator) network was deployed in San Luis Valley, Colorado, in late 2019 to provide calibration/validation soil moisture data for the CYGNSS (Cyclone Global Navigation Satellite System) mission. (Principal Investigator: Dara Entekhabi, MIT)

▶ **Rusbeh Akbar, a project co-investigator, helping install a SoilSCAPE sensor node. Credit: MIT**

High Spectral Resolution Lidar

The High Spectral Resolution Lidar - 2 (HSRL-2) instrument was selected by NASA's Aerosol Cloud meTeorology Interactions oVer the western ATlantic Experiment (ACTIVATE) project, an Earth Venture Suborbital - 3 mission that kicked off in 2019 to provide globally-relevant data about changes in marine boundary layer cloud systems, atmospheric aerosols, and multiple feedbacks that warm or cool the climate. (Principal Investigator: Chris Hostetler, NASA LaRC)

ACTIVATE will study the atmosphere over the western North Atlantic Ocean and sample its broad range of aerosol, cloud, and meteorological conditions using joint flights with two aircraft based at NASA's Langley Research Center. As an integral part of ACTIVATE, a suite of modeling tools and analysis techniques will be employed to inform preflight planning, perform data analysis, and climate model uncertainty quantification and improvement.

Compact Adaptable Microwave Limb Sounder

CAMLS undergoing testing at JPL Table Mountain. Credit: Nathaniel Livesey / JPL

Technologies developed for the Compact Adaptable Microwave Limb Sounder (CAMLS) project, an Instrument Incubator Program award that began in 2013, are being utilized for the Airborne-Scanning Microwave Limb Sounder (A-SMLS) instrument. A-SMLS has been selected for continued development under NASA's Airborne Instrument Technology Transition (AITT) program with the goal of making wide-swath measurements of atmospheric composition, water vapor, and cloud ice in the upper troposphere/lower stratosphere from the NASA ER-2 aircraft. (Principal Investigator: Nathaniel Livesey, NASA JPL)

GOAL 3
Enable a new science measurement or significantly improve the performance of an existing technique.

Vapor In-cloud Profiling Radar (VIPR)

The water vapor in Earth's atmosphere drives weather and, as a primary greenhouse gas that traps more heat than carbon dioxide, is a critical component of the climate system. As it moves around the globe, water vapor transports heat from the tropics through the mid latitudes to the polar regions, bringing rainfall and moderating temperatures. Water vapor in the atmosphere has long been measured by infrared and microwave radiometers in space and on the ground. The microwave radiometers are tuned near 183 GHz, a spectral region with a strong water vapor absorption line. But these instruments have trouble when clouds drift into view and bias their measurements.

The Vapor In-Cloud Profiling Radar (VIPR) is an emerging instrument that is attempting to tackle this problem. VIPR also uses the 183 GHz line, but unlike other radiometers, it actively emits microwaves to accurately observe inside of clouds using a differential absorption technique – it measures radar backscatter both near the peak and at a second wavelength of lower absorption to calculate the water vapor content of the clouds. In other words, VIPR can see inside and through any clouds that happen to be in the way.

Developed at the Jet Propulsion Laboratory, VIPR was put through several ground demonstrations in 2018 and 2019, culminating with test flights from November 2019 through January 2020. Aboard a Twin Otter aircraft out of Grand Junction, Colorado, VIPR completed over 44 hours of flights over landscapes as varied as the Nevada desert and the coastal regions of California. The flights also took VIPR over balloon-borne radiosonde launch sites to perform validation exercises.

Although data analysis is ongoing, preliminary review indicates the first ever combined profiles of humidity and clouds measured from an aircraft. VIPR has also been selected by the NASA Airborne Instrument Technology Transfer (AITT) program for integration onto a more capable aircraft with the aim of regular observations alongside complementary instruments. If all goes well, VIPR could soon be put into regular service measuring water vapor, even on cloudy days.

◄ PI Matt Lebsock sitting next to the VIPR instrument after it was loaded aboard a Twin Otter aircraft. Credit: Jet Propulsion Laboratory

Advanced Information Systems Technology

Advanced information systems play a leading role in the collection, processing, integration, analysis, and understanding of the vast amounts of Earth science data, both in space and on the ground. Advanced computational systems and technology concepts that enable novel acquisition, transmission, and analytics strategies for terabytes of diverse data are essential to NASA's vision of a distributed observational network. ESTO's **Advanced Information Systems Technology (AIST)** program employs an end-to-end approach to develop these critical technologies — from space where the information pipeline begins, to the end user where knowledge is advanced. AIST is currently focusing on the two following areas:

Analytic Center Frameworks

Once Earth observing missions are in operation, we can expect a lot of data back on land. Data from different missions often have different formats and diverse resolutions that, when combined with ground-based and airborne-derived data, provide comprehensive information that can improve science understanding. Scientists can utilize these agile analytic frameworks, which enhance and enable focused science investigations using disparate datasets and pioneering visualization and analytics tools including Machine Learning as well as relevant computing environments.

New Observing Strategies

With each new Earth science measurement comes a new observing system design. This thrust helps develop and evolve new ways of designing an Earth observation system to incorporate technological advances, like smaller satellites and smarter sensors, and information dynamically gathered from space, air and ground-based sources. We have more observation capabilities and tools than ever before, providing researchers with an arsenal of data-collecting possibilities. This thrust aims to develop architectures that could autonomously coordinate and integrate data from sensorwebs, including small satellites, and UAVs. Technology advances are creating opportunities to make these new measurements and to continue others more effectively.

51 Projects Active in FY20

20 Projects Graduated

VISAGE: Visualization for Integrated Satellite, Airborne, and Ground-based data Exploration – Helen Conover, The University of Alabama in Huntsville

Autonomous Moisture Continuum Sensing Network – Dara Entekhabi, MIT

ASTERIA Experiment with AWS Groundstations – Lorraine Fesq, NASA JPL

A science and applications driven mission planning tool for next generation remote sensing of snow – Barton Forman, University of Maryland

SpaceCubeX: On-board processing for Distributed Measurement and Multi-Satellite Missions – Matthew French, USC ISI

Simulation-Based Uncertainty Quantification for Atmospheric Remote Sensing Retrievals – Jonathan Hobbs, NASA JPL

OceanWorks: Ocean Science Data Platform – Thomas Huang, NASA JPL

In-space Validation of Earth Science Technologies

NASA's vision for future Earth observations necessitates the development of emerging technologies capable of making new or improved Earth science measurements. Promising new capabilities, however, bring complexity and risk, and for some technologies there remains a critical need for validation in the hazardous environment of space. ESTO's **In-Space Validation of Earth Science Technologies (InVEST)** program facilitates the space demonstration of technology projects that cannot be sufficiently evaluated on the ground or through airborne testing. Once validated in space, technologies are generally more adoptable, even beyond their intended use.

10 Projects Active in FY20

1 Project Graduated

CubeRRT: CubeSat Radiometer Radio Frequency Interference Technology Validation – Joel Johnson, The Ohio State University

Enabling multi-platform mission planning and operations simulation environments for adaptive remote sensors – Joel Johnson, The Ohio State University

Estimations of fuel moisture content for improved wildland fire spread prediction – Branko Kosovic, UCAR

HY-LaTiS: Evolving the functional data model through creation of a tool set for hyperspectral image analysis – Doug Lindholm, University of Colorado Boulder

Radiation-Tolerant Neuromorphic Processor Study – Mike Lowry, NASA ARC

Advanced Phenology Information System (APIS) – Thomas Maiersperger, USGS

Multi-Instrument Radiative Transfer and Retrieval Framework – James McDuffie, NASA JPL

Automated protocols for generating very high-resolution commercial validation products with NASA HEC resources – Christopher Neigh, NASA GSFC

Framework for Mining and Analysis of Petabyte-size Time-series on the NASA Earth Exchange (NEX) – Rama Nemani, NASA ARC

Simplified, Parallelized InSAR Scientific Computing Environment – Paul Rosen, NASA JPL

Spectral data discovery, access and analysis through EcoSIS toolkits – Philip Townsend, University of Wisconsin

Generalizing Distributed Missions Design Using the Trade-space Analysis Tool for Constellations (TAT-C) and Machine Learning (ML) – Jonathan Verville, NASA GSFC
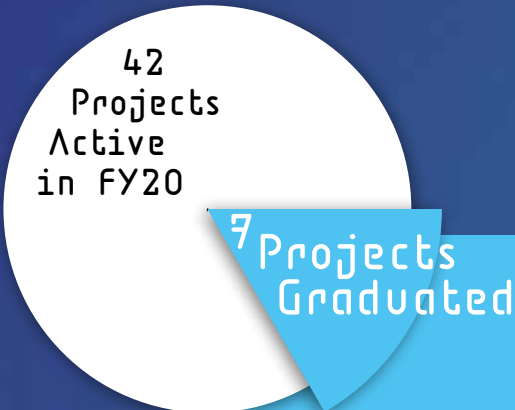
Climate risks in the water sector: Advancing the readiness of emerging technologies in climate downscaling and hydrologic modeling – Andrew Wood, NCAR

JAWS: Justified AWS-like data through workflow enhancements that ease access and add scientific value – Charlie Zender, University of California Irvine

Observation Tech

Carefully developed instrument and component technologies can reduce the risk and cost of new scientific observations with extended capabilities. ESTO's strategy for observation technologies focuses on new measurement approaches that can enable improved science capabilities and technologies to reduce the overall volume, mass, and operational complexity in observing systems. Developing and validating novel observation technologies before mission development improves their acceptance and infusion by mission planners and significantly reduces cost and schedule uncertainties. ESTO's Observation Technology investments are divided among three main programs: the Instrument Incubator Program, Advanced Component Technologies, and Sustainable Land Imaging-Technology.

Advanced Component Technologies

Advanced Component Technologies (ACT) implements technology developments to advance state-of-the-art instruments. The ACT program funds the research, development, and demonstration of component- and subsystem-level technologies to reduce the risk, cost, size, mass, and development time of missions and infrastructure.

15 Projects Active in FY20

2 Projects Graduated

Correlator Array-Fed Microwave Radiometer Component Technologies – Jeffrey Piepmeier, NASA Goddard Space Flight Center

A Black Array of Broadband Absolute Radiometers (BABAR) for Spectral Measurements of the Earth – Michelle Stephens, NIST
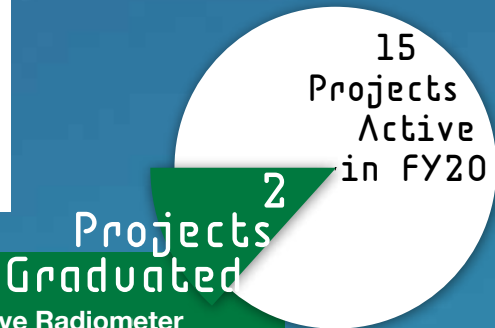
Instrument Incubator Program

The Instrument Incubator Program (IIP) provides funding for new instrument and observation techniques, from concept to breadboard and flight demonstrations. Instrument technology development of this scale, outside of a flight project, consistently leads to smaller, less resource-intensive instruments that reduce the costs and risks of mission instrumentation.

42 Projects Active in FY20

7 Projects Graduated

H2O, CH4, and HSRL Airborne Lidar Observations (HALO) – Amin Nehrir, NASA Langley Research Center

Wide-band Millimeter and Sub-Millimeter Wave Radiometer Instrument to Measure Tropospheric Water and Cloud ICE (TWICE) – Steven Reising, Colorado State University

Multi-wavelength Ocean Profiling and Atmospheric Lidar – Chris Hostetler, NASA Langley Research Center

Chrisp Compact VNIR/SWIR Imaging Spectrometer Development – Ronald Lockwood, MIT Lincoln Lab

MiniSpec: Miniaturized Imaging Spectrometer to Measure Vegetation Structure and Function – Jon Ranson, NASA Goddard Space Flight Center

Development and Demonstration of an Airborne Differential Absorption Radar for Humidity Sounding Inside Boundary Layer Clouds – Matthew Lebsock, Jet Propulsion Laboratory

SRI CubeSat Imaging Radar for Earth Science: Instrument Development and Demonstration (CIRES-IDD) – Lauren Wye, SRI International

Sustainable Land Imaging - Technology

For over 40 years, the Landsat series of satellites has been providing a continuous stream of moderate resolution, multispectral images that have been used by a broad range of specialists to analyze our world. To continue the mission of Landsat, NASA initiated the **Sustainable Land Imaging – Technology (SLI-T)** program to explore innovative technologies to achieve Landsat-like data with more efficient instruments, sensors, components, and methodologies.

The SLI-T program added six projects in July through a competitive solicitation that sought technology development activities aimed specifically at: (1) demonstrating improved, innovative, full-instrument concepts for potential infusion into the architecture and design of missions beyond Landsat-10; and (2) development and technical maturation at the component and/or breadboard-level of technologies that have long-term potential to significantly improve future land imaging instruments and systems through substantial architecture changes. The six new awards are as follows:

12 Projects Active in FY20

6 Projects Added in FY20

Super Uncooled Multi-Band Radiometer Sensor (SUMRS) – Philip Ely, DRS Network & Imaging Systems, LLC

Land Calibration Satellite Breadboard – Geir Kvaran, Ball Aerospace & Technologies Corporation

TransCal: An Innovative, Highly Accurate, Transmissive Radiometric Calibration Approach – Nathan Leisso, Ball Aerospace & Technologies Corporation

Improved Radiometric Calibration of Land Imaging Systems (IRIS) – Jeffery Puschell, Raytheon

Versatile Computational Pixel Infrared Land Imager – David Ting, Jet Propulsion Laboratory

Reduced Envelope Multispectral Infrared Radiometer (REMIR) – Michael Veto, Ball Aerospace & Technologies Corporation

New NASA radar looks to monitor volcanoes and earthquakes from space

To help monitor ground deformation from space, ESTO-PI Lauren Wye developed a new technology equipped with an S-band Interferometric Synthetic Aperture Radar (InSAR) for a small satellite platform.

A global map detailing land elevation changes over time can help scientists pinpoint ground motion before, during, and after earthquakes and volcanic eruptions and help identify impacts from floods and groundwater pumping. This new instrument aims to head to space on a small satellite to capture that information for decision makers, scientists, and others.

"The CubeSat Imaging Radar for Earth Sciences, or CIRES, can help decision-makers and emergency managers obtain observations sooner after a hazardous event so that they are better prepared to deal with disaster relief," said Wye, who recently concluded CIRES's development at SRI International in Menlo Park, California.

CIRES's S-band radar is able to penetrate through vegetation and reach the ground. CIRES takes two radar images of a specific area from approximately the same position in space at two different times and then processes the two images to determine the difference between them.

◄ The team flew CIRES over the Kilauea volcanic eruption June 30th to July 5th, 2018, to validate the instrument. InSAR measurements of active summit deformation can have a direct impact on the surrounding community.
Credit: Lauren Wye / SRI International

▼ In December 2019, CIRES was mounted on a Cessna 208 aircraft for a collection campaign over the Muscatatuck Urban Training Center (MUTC) in Indiana to demonstrate detection of sub-cm surface deformations and to evaluate the ability of the CIRES instrument to determine flood inundation levels in an urban environment. CIRES collected data over the controlled flooding facility both before and after the flooding event. The pictured image covers 4 x 8 km at a resolution of 5 meters. Credit: Patrick Rennich / SRI International

# A New Algorithm Aims to Help Better Predict Wildland Fires

Wildland fires' towering orange and yellow flames consume trees and vegetation. They can benefit the environment by reducing the grass, brush, and trees that would fuel larger, even more intense fires while also improving wildlife habitat. Conversely, when the fires are in the wrong place at the wrong time, they can create devastation for nearby communities and cultural resources.

To better predict how wildland fires will spread, a team of researchers created a machine learning algorithm that predicts fuel moisture content, or the likeliness of vegetation to burn, based on satellite observations.
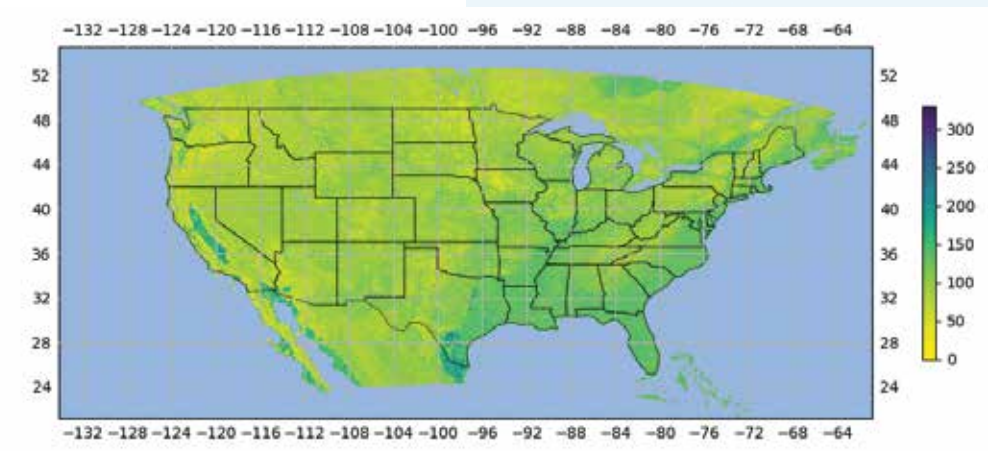
"One thing that's really exciting is being able to make the connection between remote sensing and machine learning," Branko Kosovic, the Director of the Weather Systems and Assessment Program at the National Center for Atmospheric Research in Boulder, Colorado and the project's lead investigator, said. Combining the two tools allows decision makers to get better coverage of fires across the United States.

▲ Wildland fire spread models are particularly sensitive to Fuel Moisture Content (FMC). Prior to this project's development, FMC data was updated from sparse samples and at varying time intervals. The project's daily 1km gridded FMC product is now publicly available and used by the Colorado Fire Prediction System. This image shows the 1km gridded dead FMC product from Sep. 27, 2020. The increased moisture content in California's heavily irrigated Central Valley is a striking feature. Credit: Branko Kosovic / NCAR
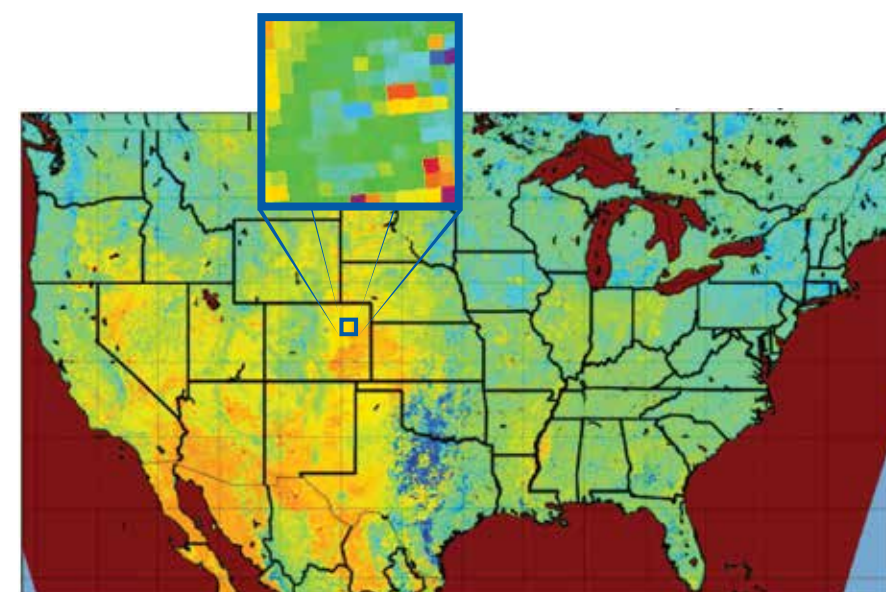
◄This project uses machine learning to combine MODIS Aqua and Terra satellite observations, National Water Model output, and terrain data with surface observations to estimate dead and live FMC over the continental US to produce a gridded, 1 km resolution, FMC map every day. The map to the left is from July 9, 2016—the day of the Cold Spring Fire in Colorado. Credit: Branko Kosovic / NCAR

# CubeSat takes Earth's temperature from space
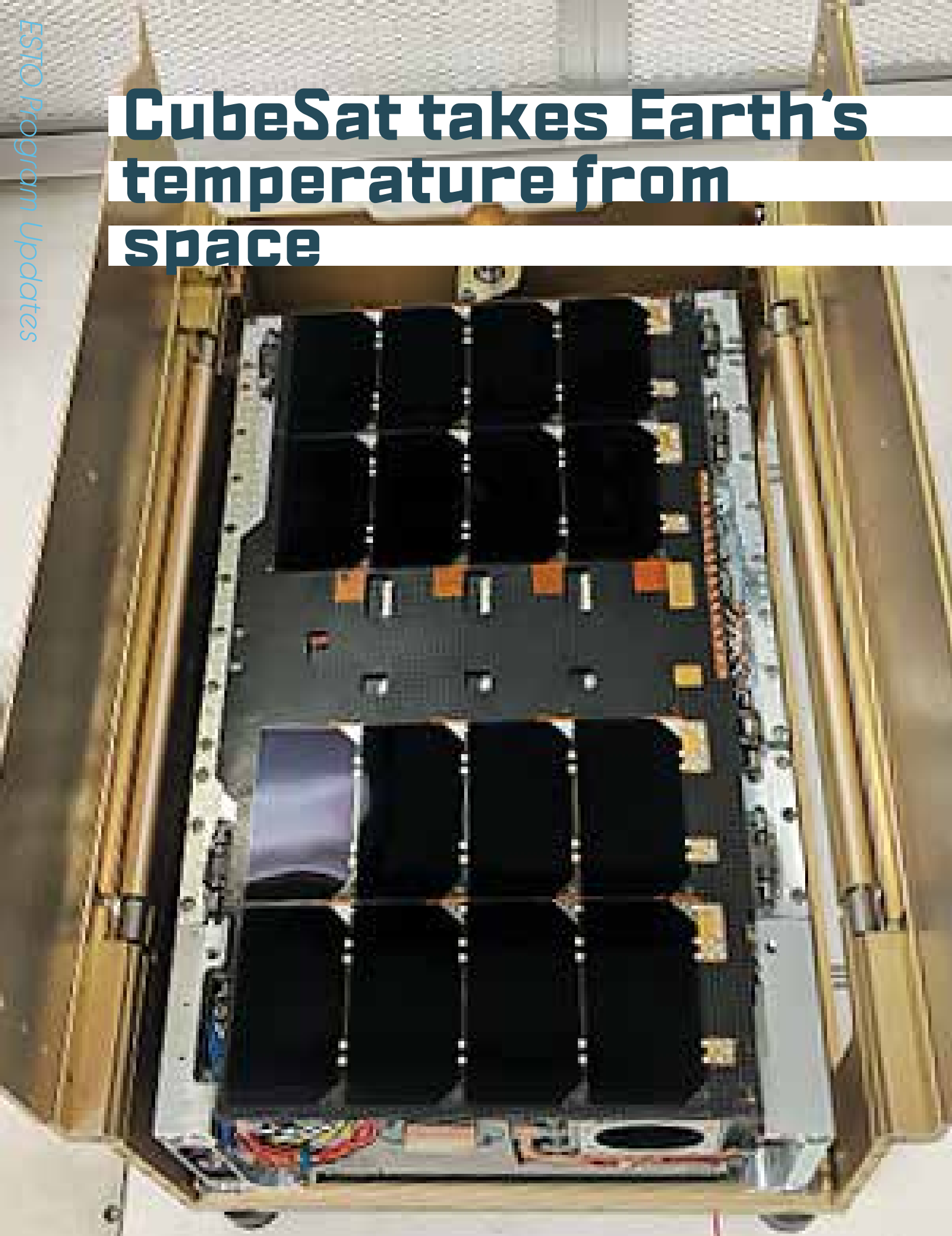
The Compact Infrared Radiometer in Space instrument on a CubeSat, also known as CIRiS, launched from Cape Canaveral Air Force Station in Florida to the International Space Station on Dec. 5, 2019.

The backpack-sized satellite is collecting, processing, and calibrating infrared images, which reveal Earth's temperature for the first time from a small satellite. "If we can do this, we have greatly increased the value of the data for Earth Science applications, as well as land and water management," David Osterman, the CIRiS Principal Investigator at Ball Aerospace, said.

Farmers could use CIRiS's data as they determine if a field of oranges needs more water or if a grove of almond trees is too wet. CIRiS aims to demonstrate new capabilities to complement future

NASA Earth-observing missions, increasing the frequency of image collection at a potentially reduced size and cost. "We're looking to achieve high performance in everything while still fitting into a small space," Osterman said.

Even before CIRiS left Earth, NASA funded its sibling, L-CIRiS, also to be built by Ball Aerospace, which has an "L" for lunar, to head to the Moon and use similar instruments to identify minerals on the Moon. L-CIRiS was selected as part of NASA's Artemis lunar program, which will help NASA send astronauts to the Moon by 2024 as a way to prepare to send the first humans to Mars.
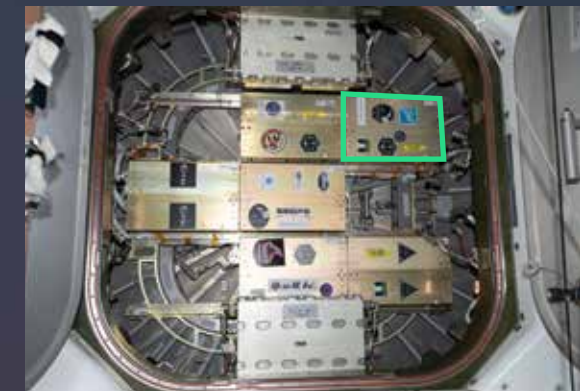
▲ **CIRiS arrived at the Space Station on December 8, 2019, and after a two month stay, was packed into a CYGNUS spacecraft to be deployed at the orbital altitude of 470 km. CIRiS is shown above in the CYGNUS dispenser outlined in green.**

▼ **CIRiS acquired its first Earth images while passing over the South Indian Ocean off the southern coast of Australia on June 17, 2020. This image below shows the three infrared bands CIRiS captures. Credit: David Osterman / Ball Aerospace**
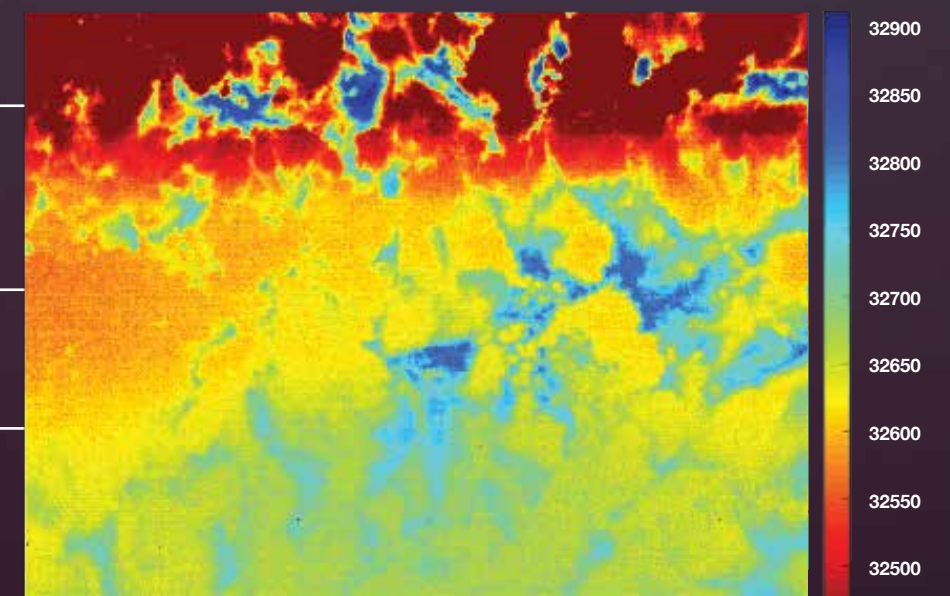

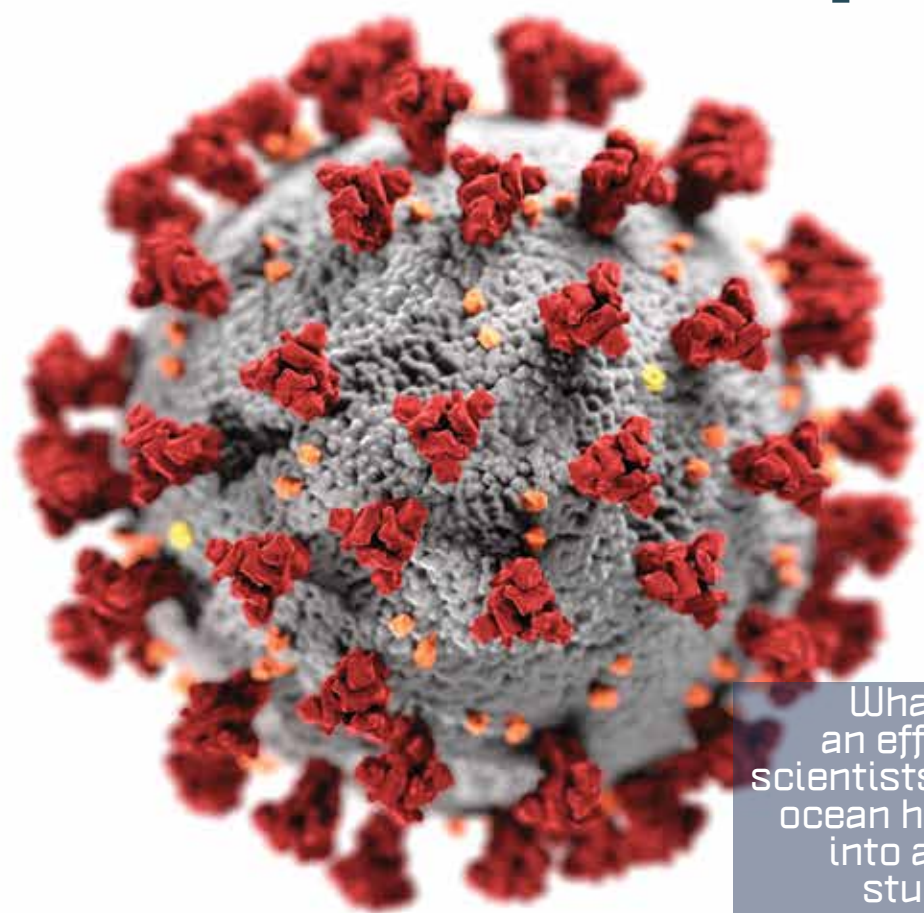**Full-Width Half-Maximum Wavelength (Lower, Upper)**

Band 1: 7.40 µm, 13.72 µm

Band 2: 9.85 µm, 11.35 µm

Band 3: 11.77 µm, 12.60 µm

32900
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From Ocean Science to COVID-19: An Algorithm Finds a New Purpose

What began as an effort to help scientists study the ocean has evolved into an effort to study a global pandemic.

In 2015, Chaowei Phil Yang, a professor at George Mason University in Fairfax, Virginia, set out to develop a new Google-like search portal to help scientists effectively search and discover oceanographic data collected by satellites, airplanes, and water-based sensors.

The portal, called Mining and Utilizing Dataset Relevancy from Oceanographic Dataset (MUDROD) uses machine learning algorithms to better understand and respond to its users' queries about the ocean. MUDROD was funded by ESTO and made available to the public in 2017.

Approximately three years later, when cases of COVID-19 began to spread rapidly around the world, Yang turned to MUDROD's algorithms to analyze the growing data about the deadly virus. Instead of learning oceanographic lingo, MUDROD's machine learning algorithms began learning about COVID-19.

Yang and his team updated MUDROD's algorithm for the COVID-19 Spatiotemporal Rapid Response Gateway to pull information and trends out of COVID-19 data and news stories. The gateway helps users explore how death and infection rates are changing in real-time, how different countries are responding to quarantine restrictions, how people changed their travel patterns in response to government guidelines, how companies changed their hiring and layoffs during lockdowns, how reporters are covering the pandemic, and how air quality changed during the winter, spring and summer of 2020.

The gateway's algorithms parse multiple public health and government datasets, as well as peer reviewed scientific publications and news reports around the world. "Our machine learning algorithm, at its core, aims to solve a big spatiotemporal data problem," Yang said.

▼ **For more information, visit: https://covid-19.stcenter.net/**

NASA, New Zealand Partner to Collect Climate Data from Commercial Aircraft

An ESTO PI partners with Air New Zealand to generate new data that will drive innovations .

NASA is partnering with the New Zealand Ministry of Business, Innovation and Employment, New Zealand Space Agency, Air New Zealand, and the University of Auckland to install next-generation Global Navigation Satellite System (GNSS) reflectometry receivers on passenger aircraft to collect environmental science data over New Zealand.

The program is part of NASA's Cyclone Global Navigation Satellite System (CYGNSS) mission, a constellation of eight small satellites, launched in 2016, that use signals from Global Positioning System (GPS) satellites that reflect off Earth's surface to collect science data.

The CYGNSS satellites orbit above the tropics and their primary mission is to use GPS signals to measure wind speed over the ocean by examining GPS signal reflections off choppy versus calm water. This allows researchers to gain new insight into wind speed over the ocean and will allow them to better understand hurricanes and tropical cyclones.
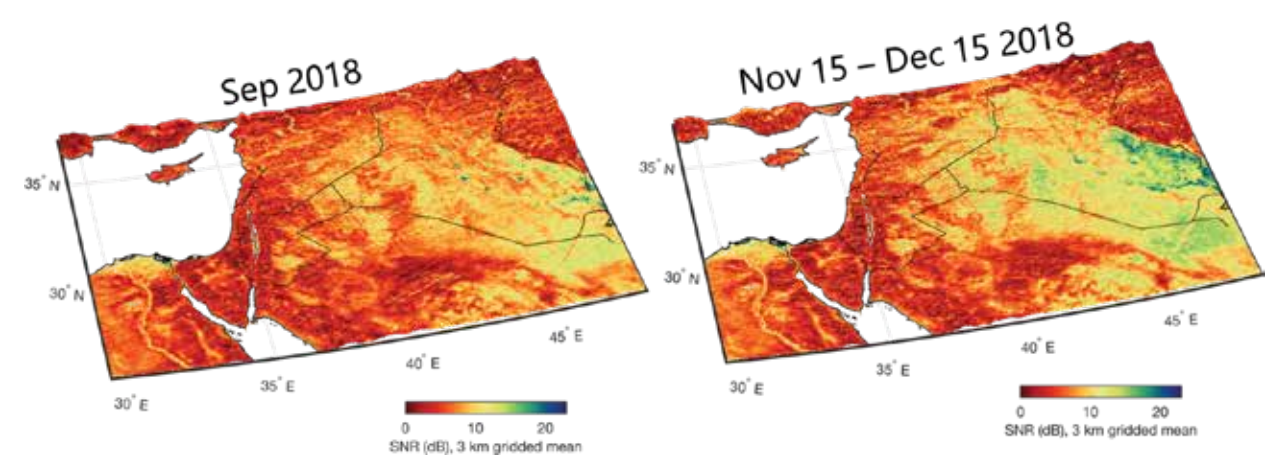
The CYGNSS team, led by principal investigator Chris Ruf at the University of Michigan in Ann Arbor, has developed a next-generation GNSS reflectivity receiver with support from ESTO. These receivers will be installed in late 2020 on one of Air New Zealand's Q300 domestic aircraft.

As the aircraft traverses New Zealand, it will collect data from the land below, some of which will overlap with the flight paths of the CYGNSS satellites. This overlap, which will have frequent data observations from regular commercial flights, will provide the CYGNSS team a wealth of data to use to validate and improve the CYGNSS satellite observations, said Ruf. In addition, the varied New Zealand terrain will provide comparison points with data collected in similar terrains in other parts of the world.
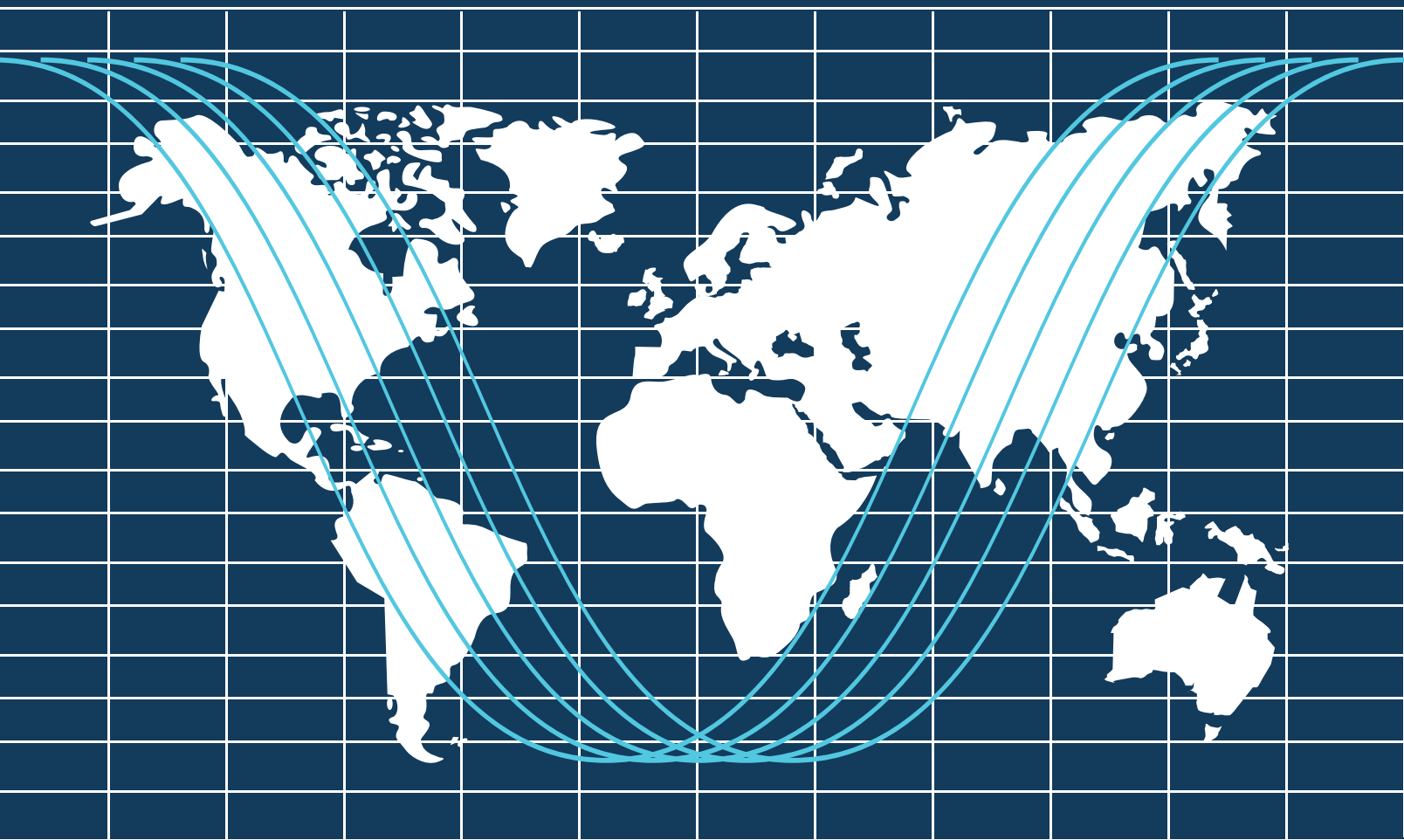

▲ Chris Ruf inspects one of the CYGNSS Satellites before it is deployed into orbit. Credit: NASA

▼ The data below show a major flood event in northwest Iraq caused by heavy precipitation in Nov 2018. On the left, a CYGNSS signal-to-noise ratio (SNR) map for September 2018, before flooding. On the right, a map from November-December 2018 identifies flooded regions by large increases in SNR (yellow-green areas). Credit: Clara Chew / UCAR

One of Air New Zealand's Bombardier Q300 domestic aircraft. Credit: Air New Zealandd

Sep 2018

Nov 15 – Dec 15 2018

Government Release of the Trade-space Analysis Tool for Designing Constellations (TAT-C)

The Trade-space Analysis Tool for designing Constellations (TAT-C) provides a framework to explore new ways to design Earth science missions. The software allows the user to ask questions, such as:

- Which type of constellations should be chosen?
- How many spacecraft should be included in the constellation?
- Which design has the best cost/risk value?

TAT-C will address the strong and growing interest in implementing future NASA Earth Science missions as Distributed Spacecraft Missions (DSMs), particularly with SmallSats. The goal is to provide the Earth science community with a powerful tool to quickly design novel DSMs or augment existing missions to optimize their science return. The software facilitates DSM Pre-Phase A investigations and optimizes DSM designs with respect to a-priori science goals.

TAT-C's modular architecture includes a knowledge base, a cost and risk module, an orbit and coverage module, an instrument module, a launch module, a maintenance module, and a carefully designed trade-space search iterator and user interface. TAT-C enables users to quickly assess, visualize, and validate a very large number of potential architectures in response to input and output science requirements.

HOW DO I ACCESS THE SOFTWARE?

The first version of the TAT-C software is now available for government release and can be obtained on the NASA Software Catalog website. Instructions follow:

1. Visit: https://software.nasa.gov/ and search for "Trade-space Analysis Tool for designing Constellations" or "TAT-C".

2. Click the "Download Now" button. This will take you to the online software usage agreement (SUA) that will need to be filled out. Even government purpose software is distributed using the SUA process.

Prototype Ozone Monitoring Instrument Undergoes Sun-Look Testing

A prototype of an ESTO-funded instrument that could one day extend NASA's data record of Earth's ozone layer recently got its first glimpse of the Sun.

A team at NASA's Langley Research Center in Hampton, Virginia, recently took the Stratospheric Aerosol and Gas Experiment (SAGE) IV Pathfinder onto the roof of one of the center's buildings to conduct Sun-look tests.

These tests are critical for an instrument that makes measurements of ozone and tiny atmospheric particles called aerosols by looking at the light from the rising or setting Sun as it passes through Earth's atmosphere — a technique called solar occultation. Prior to being brought outside, SAGE IV Pathfinder had undergone months of testing in a lab.

"There's nothing like getting out and taking a look at the Sun, which is extremely bright in comparison to anything we can produce in the laboratory," said Charles Hill, co-principal investigator for SAGE IV Pathfinder.

A full-blown SAGE IV mission would be a significant new chapter in the SAGE story, which began in the late 1970s and continued through the following decades. The data collected on SAGE I and the following instrument SAGE II, were critical to the discovery of the Earth's ozone hole and the creation of the 1987 Montreal Protocol, an international treaty that banned the use of chlorofluorocarbons (CFCs). CFCs were used as refrigerants and in aerosol spray cans and are significant contributors to stratospheric ozone depletion.

SAGE IV is in a prototype state and unlike its washing-machine-sized predecessors would fit neatly within the confines of a CubeSat that's not much bigger than an average shoe box. That reduction in size, which comes from an improved measurement technique that images the entire Sun rather than looking at only a small portion of it, would make it more cost effective.

▼ **Charles Hill, left, and John Leckey with the SAGE IV Pathfinder instrument during Sun-look testing at NASA's Langley Research Center Credits: NASA / David C. Bowman**

ESTO Fosters Innovative Ways to Understand Biodiversity

To study and monitor changes in Earth's biodiversity, or the immense volume of organisms in the world, scientists and citizen scientists record their sightings in the field. At the same time, sensors on the ground and on board satellites and aircraft monitor flora and fauna on a regional to global scale.

ESTO funded four projects to create new, virtual portals that bring this wealth of biodiversity information into focus to help inform scientists, land managers, and decision makers around the world regarding the status and health of terrestrial ecosystems.

Each of these projects highlights a different aspect of biodiversity and lets users create easy-to-use maps and other information products to track healthy and vulnerable species as they compete for resources, migrate to safer habitats, and adapt to climate change.

Where are the plants and animals?

If you've ever spotted a bright green frog with tiger stripes and wondered, what is that and how can I find more of them, you're in luck. Tiger-striped leaf frogs are one of many species included in the Map of Life, an interactive virtual database that tracks mammals, birds, reptiles, amphibians, and some fish, insect and plant species around the world. The database can also forecast where species will live in the future and help you determine if their habitats will be protected by laws and regulations.

"As the world around us changes rapidly, society, policymakers, businesses, and individuals need to make decisions about how we engage with the environment," said Walter Jetz, a professor at Yale University leading the Map of Life effort. "The data is rapidly increasing," Jetz said.

To explore species range maps, habitat loss, biodiversity trends, and more, learn more about this project at: **www.mol.org**.

How are communities of species impacted by climate change?

Researchers at Duke University in Durham, North Carolina, are also creating a tool to help identify biodiversity changes in North America. In particular, the team, led by Jennifer Swenson and Jim Clark, both professors at Duke, want to know how one species could impact another as it relocates and competes for suitable habitats in a warming world. The team created an interactive web portal that pulls together satellite, airborne and ground-based information, as well as climate projections and ecological forecasts, to track how climate change will impact species and wildlife communities.

For instance, the Predicting Biodiversity with a Generalized Joint Attribution Model, or PBGJAM, used information gathered by the National Ecological Observatory Network (NEON) and NASA's remotely sensed Earth data and climate data, among other sources, to reveal where pileated woodpeckers, desert pocket mice and white fir trees, among many species, could migrate under future climate scenarios.

"We need to consider who's living with whom in order to understand larger impacts," said Swenson. For instance, if the desert pocket mice don't survive a drought, will their predators find other sources of food, change locations or also perish?

PBGJAM's species maps and models can be found at: **pbgjam.env.duke.edu**.

When will things bloom?

While PBGJAM takes a broad approach to studying climate change impacts on communities of species, the Advanced Phenological Information System (APIS) focuses on the seasonal dynamics of plant species. More specifically, APIS provides a framework to explore how climate change and other factors can impact phenology, or the study of seasonal life-cycle events such as leafing, flowering, reproduction and migration.

APIS includes a constellation of software that relies on millions of field-based observations, near surface cameras, and satellite data to explore and synthesize phenology observations from different times and on various spatial scales. The effort was co-led by Jeff Morisette, Chief Scientist for the National Invasive Species Council and Tom Maiersperger, Project Scientist for the Land Processes Distributed Active Archive Center. The center is part of NASA's Earth Observing System Data and Information System and is located at the U.S. Geological Survey's Earth Resources Observation and Science Center in Sioux Falls, South Dakota.

What are plants' colors telling us?

To help supply APIS, PBGJAM, and the Map of Life with robust plant data, a team led by Phil Townsend created the Ecological Spectral Information System (EcoSIS). Townsend is a professor at the University of Wisconsin-Madison.

The EcoSIS database is a one-stop portal to add, discover, and use spectral data. "Spectral information is an indicator for biodiversity," Natasha Stavros, an engineer working with Townsend at NASA's Jet Propulsion Laboratory, said.

Explore this tool and find spectral data at: **ecosis.org**.

Tiny Satellite Captures First Images of Clouds and Aerosols

Lake Titicaca

Uyuni Salt Flats

The Hyper-Angular Rainbow Polarimeter (HARP) CubeSat achieved "first light" on April 16, 2020. The tiny satellite sent back its very first image over Europe with bright splashes of colors defining clouds and aerosols, which are tiny particles in the atmosphere. HARP's measurements help us better understand how clouds and aerosols impact weather, climate, and air quality.

HARP filters light into four wavelengths and uses a prism to rotate that light to three polarization angles. Just as polarized sunglasses help block bright light of a specific polarization to help you see past the sun's glare, HARP can block certain wavelengths and make observations from many angles. The CubeSat reveals what is hidden to the naked eye: amounts and types of aerosols as well as the size of water droplets or ice particles inside clouds.

"Every time HARP flies over a region, we see that region from multiple perspectives," Vanderlei Martins, HARP principal investigator and a professor at the University of Maryland, Baltimore County, said. HARP launched to the International Space Station from NASA's Wallops Flight Facility, Virginia, on Nov. 2, 2019. In February 2020, the CubeSat floated away from the space station and began its orbit around Earth.
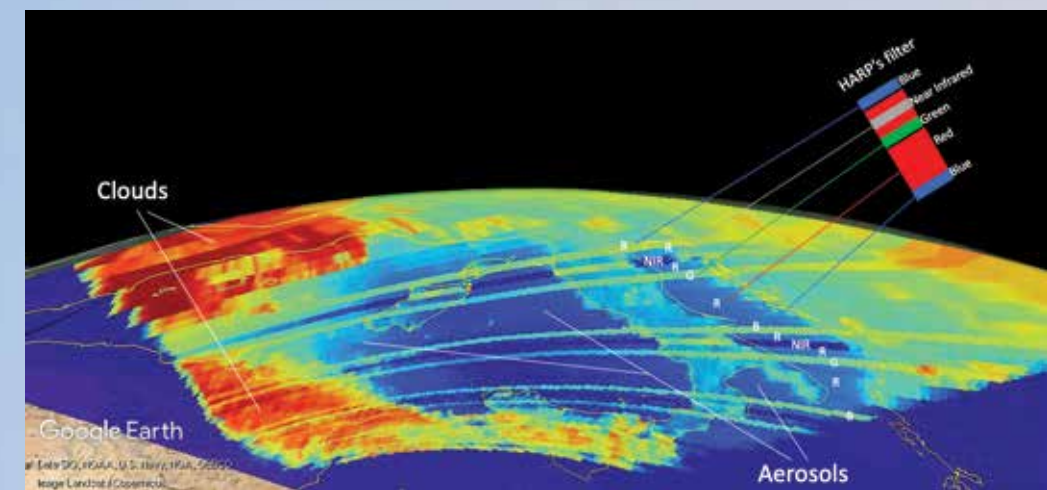
HARP marks NASA's first attempt to put a polarimeter, which measures the polarization of light, aboard a CubeSat. HARP could pave the way for future NASA missions involving a constellation of little satellites peering down at clouds and aerosols, Martins said.

HARP also inspired a successor called HARP2, which is an instrument that will fly on NASA's Plankton, Aerosol, Cloud, ocean Ecosystem (PACE) mission. HARP2 is a copy of the HARP CubeSat polarimeter payload adapted for flying and collecting data from a large spacecraft platform like PACE.

Currently under development, PACE will extend and improve NASA's 20-plus-year record of satellite observations of global ocean biology, chemistry, aerosols, and clouds. HARP2 will be able to operate all the time and collect significantly more science data than the HARP CubeSat.

Clouds

Aerosols

HARP's filter

▲ **HARP's first light image shown above, overlaid on a map of Europe. The stripes in this image emphasize the different wavelengths sampled by HARP's detector. Credit: Vanderlei Martins / UMBC**

◄ **On May 3, 2020, HARP acquired its first full push-broom image. The RGB image comprises 469 single shots from its nadir scan and measures the hyperangular sun glint profile at 670 nm. It was taken in the vicinity of Lake Titicaca. A common radiance calibration target—the Uyuni Salt Flat in Bolivia, is clearly discernible in this image. Credit: Vanderlei Martins / UMBC**

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New Tool for Ocean Data Visualization

A virtual NASA ocean portal lets you explore sea level rise around the world from your desk.

Torrential storms and fierce hurricanes push farther inland than they once did, threatening homes, roads, bridges, water supplies, and sewage treatment plants.

Extreme weather events are expected to intensify as global temperatures rise, causing glaciers and ice sheets to melt and the ocean to expand. Sea levels are rising approximately 0.13 inches (3.3 millimeters) a year. Global average sea level has risen 8 to 9 inches (21 to 24 centimeters) since 1880, with about a third of that rise occurring in the last two and a half decades.

To help scientists and decision makers study this global phenomenon and better understand its consequences, researchers at NASA's Jet Propulsion Laboratory in Southern California created OceanWorks, an accessible, interactive portal that helps users visualize sea level rise, among other ocean variables, for specific regions around the world.

"This is a first-of-its-kind data analysis tool for Earth science," Thomas Huang, the project's principal investigator based at JPL, said. "You can flip to different time periods and see how sea level is changing around the world."
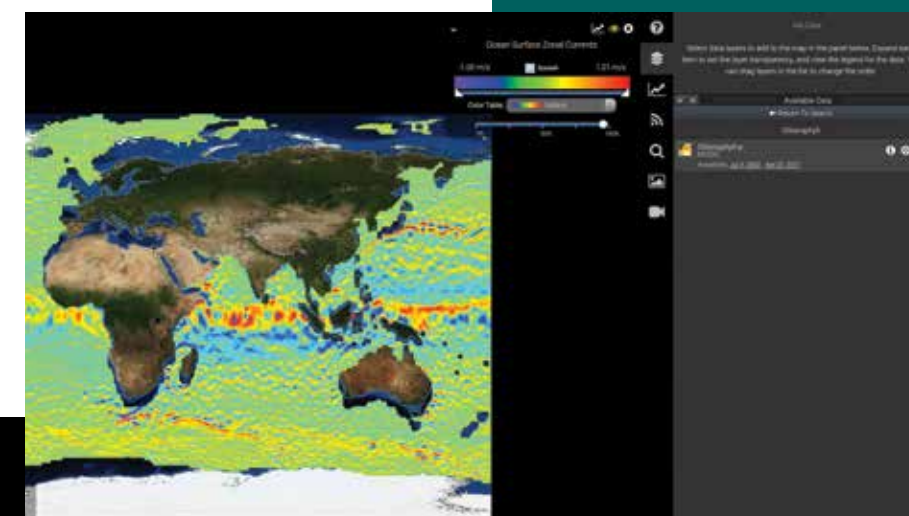
The portal's advanced algorithms digest and synthesize an immense amount of diverse data to display a comprehensive visualization of ocean currents, salinity, rain rate, ocean temperature, and sea level rise, among many variables, over a specific location.

"NASA has a broad, global view of the ocean," Ben Hamlington, a scientist at JPL and team lead of the NASA Sea Level Change Science Team, said, "and that's something that's very important for sea level science."
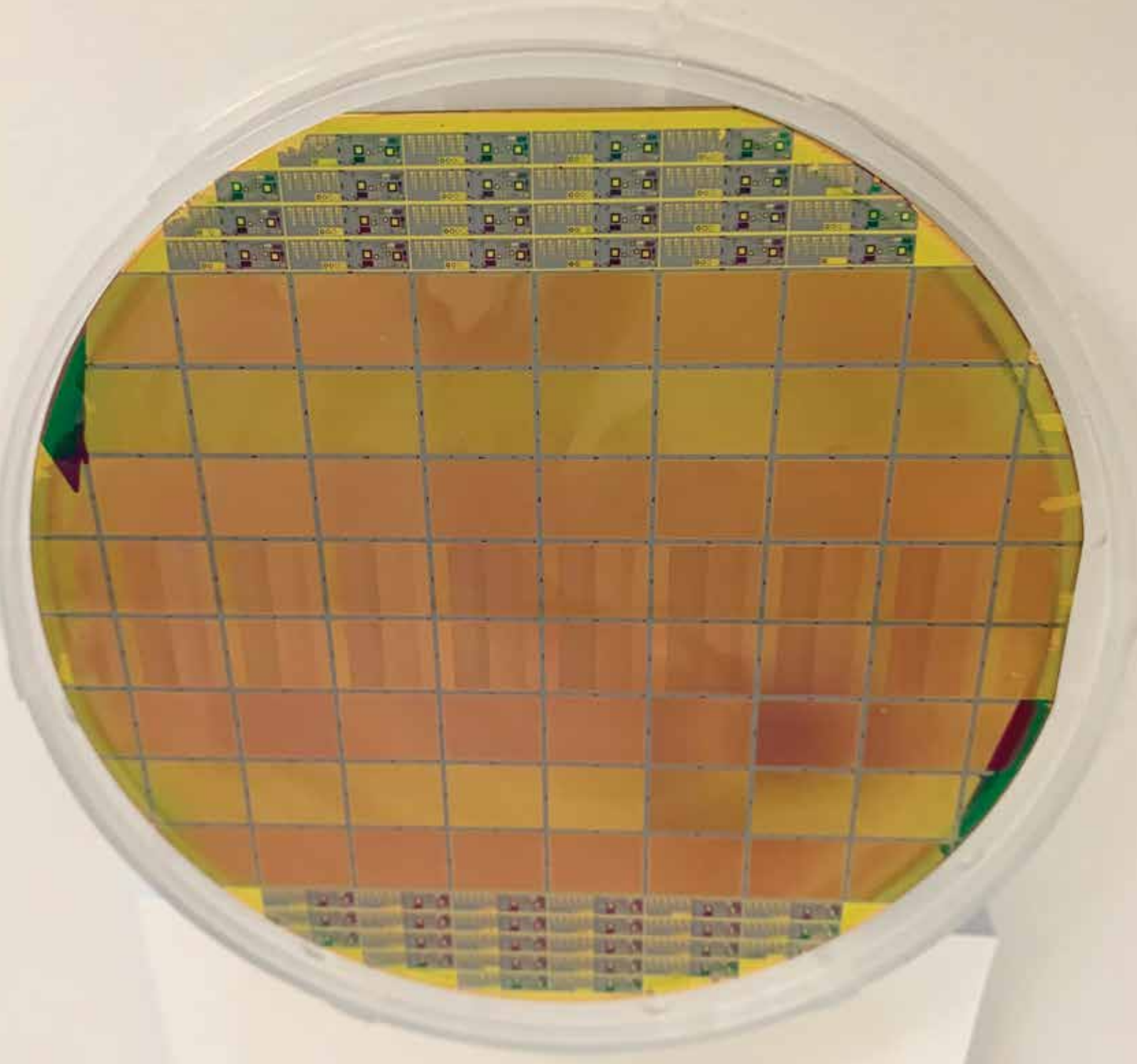
The upcoming European Science Agency (ESA) Sentinel-6A Michael Freilich satellite launch in November 2020 will add to the continuous record of sea level data since 1993. "The longer the record, the better we can see natural versus anthropogenic contributors to sea level rise," Hamlington said.
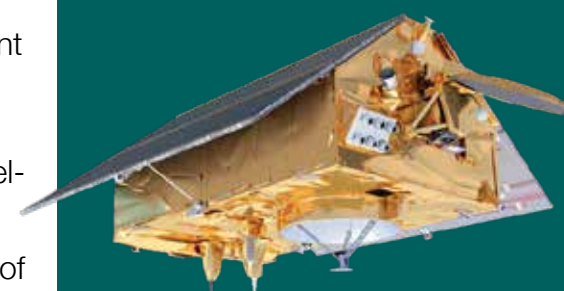
▲ The Sentinel-6A Michael Freilich will make high-precision ocean altimetry measurements and collect high-resolution vertical profiles of temperature. Credit: NASA

▶ OceanWorks data product displaying MODIS data of the geographic distribution of chlorophyll-a in October 2003. Access this tool at: oceanworks.jpl.nasa.gov/.

Toward Improved Surface Temperature Measurements

Many satellites employ infrared-sensing instruments that detect radiation emitted from the Earth's surface. The long-wave infrared (LWIR, 8-15 microns) and mid-wave infrared (MWIR, 3-8 microns) constitute the thermal region of the electromagnetic spectrum, and are used for measurements of Earth's land and sea surface temperature, as well as detection of forest fires or other features that are warmer than their surroundings.

The detectors found in these instruments need to be operated at very cold temperatures — as low as 50 Kelvin — to reduce "noise" from other sources and to deliver stable measurement performance. But the cooling hardware adds a cost to the overall satellite mission in terms of power, volume, and mass, and prevents infrared instruments from being flown on smaller platforms such as CubeSats.

A project led by Sarath Gunapala at the Jet Propulsion Laboratory is exploring several component-level technologies that could enable LWIR and MWIR focal plane arrays with significantly higher operating temperatures. Sarath and his team are utilizing barrier infrared detector (BIRD) technology along with light-trapping metasurface lenses and digital readout integrated circuits (DROICs) to increase the signal-to-noise ratio. The performance increases could allow for infrared detectors that operate at a higher temperatures, but with the same (or better) sensitivity as detectors in use today.

◀ **Metasurface LWIR detector arrays fabricated on a 4-inch GaSb substrate using a stepper lithography. Credit: Sarath Gunapala / JPL**

▶ **A 640 x 512 pixel LWIR focal plane array. Credit: Sarath Gunapala / JPL**

▼ **Scanning electron microscope image of a gallium antimonide (GaSb) metalens fabricated using e-beam lithography and chlorine and fluorine plasma etching to define the nano-pillars. These metalenses are fabricated on the backside of the focal plane array, and they have been shown to decrease dark current thereby increasing the operating temperature by 25 Kelvin. Credit: Sarath Gunapala / JPL**
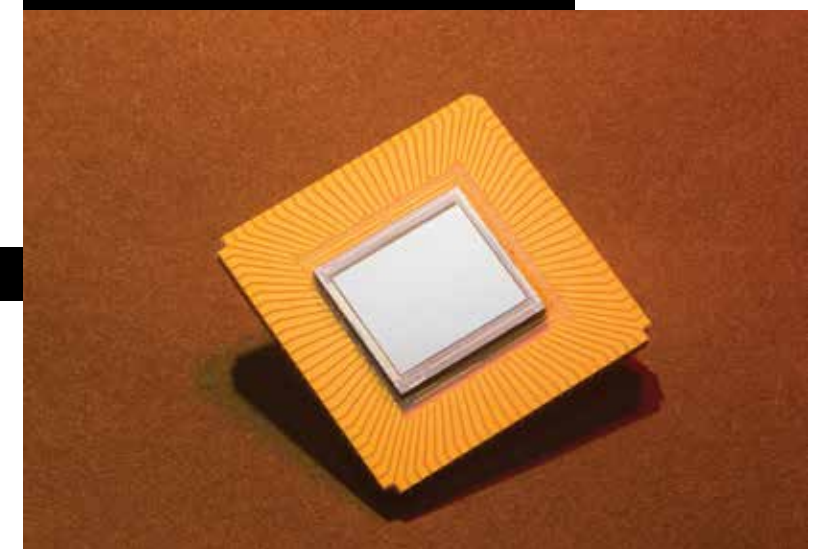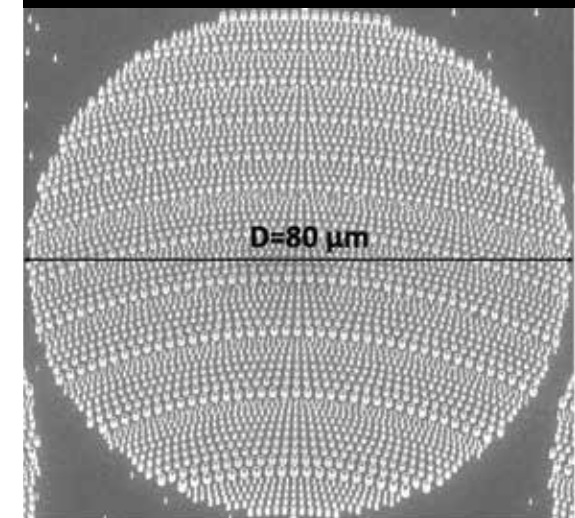
New Moon-Seeking Sensor Aims to Improve Earth Observations

A new instrument with its eye on the Moon aims to help Earth-observing sensors make more accurate measurements.

Earth-observing sensors, like the Visible Infrared Imaging Radiometric Suite (VIIRS) aboard the NASA/NOAA/DOD Suomi National Polar-orbiting Partnership satellite and the NOAA-20 meteorological satellite, collect images of cloud cover, land surface cover, and ocean color. While these sensors are diligently doing their jobs, they also have to brace against high-energy particles and withstand ultraviolet light, which degrade their sensors over time.

To account for any changes in sensitivity, VIIRS and other satellite instruments calibrate their sensors by looking at a known reference and comparing the most recent glance to previous ones. If the sensor sees the reference differently than before, it knows it needs to recalibrate or adjust its sensitivity.

Currently, many instruments use the Sun as a reference for sensor calibration. However, although the Sun provides a steady output, its harsh rays can degrade the instrument's performance over time. The Moon, on the other hand, is an ideal diffuser since its reflectance of sunlight is stable and more similar to Earth's in brightness.

The airborne Lunar Spectral Irradiance Instrument (air-LUSI) "measures how much sunlight is reflected by the Moon at various phases in order to accurately characterize it and expand how the Moon is used to calibrate Earth observing sensors", said Kevin Turpie, a research professor at the University of Maryland, Baltimore County, leading the air-LUSI effort.

Turpie and his team are funded by NASA's Earth Science Division and the National Institute of Standards and Technology with support from the US Geological Survey.

Air-LUSI's novel approach is able to obtain highly accurate lunar irradiance measurements that will have the lowest ever uncertainty (less than 1%) at a very high spectral resolution, Turpie said, which is extremely important for improving how we use the Moon to calibrate Earth-observing satellites.

If successful, this utilization of the Moon as an accurate, absolute calibration reference could lead to cheaper satellites with less on-board calibration hardware and greater consistency between satellites.

▼ The air-LUSI telescope and autonomous robotic mount is designed to acquire unprecedentedly accurate measurements of lunar spectral irradiance from an ER-2 aircraft flying at 21km altitude. Credit: Ken Ulrich / UMBC
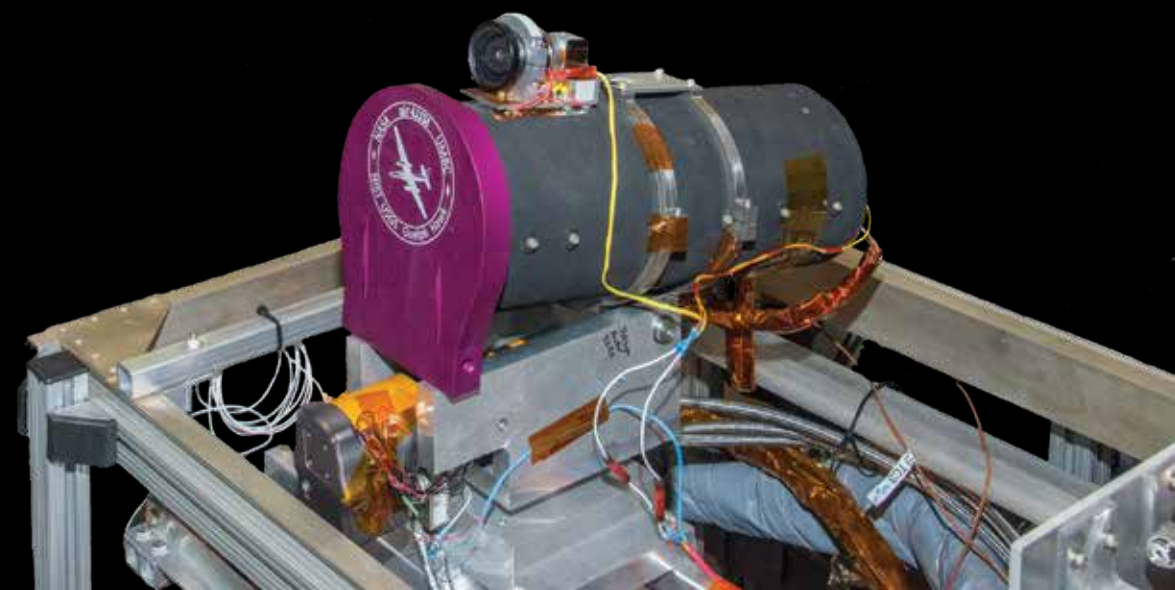
Three CubeSats Celebrate Anniversaries

Three tiny satellites that were only meant to operate for a few months are celebrating their two-year anniversaries of successful operation in orbit.

On May 21, 2018, three ESTO CubeSats were launched from NASA's Wallops Flight Facility on Wallops Island, Virginia to the International Space Station. Still a relatively new platform from which to test technologies, CubeSats typically have mission objectives to be accomplished within a quick six-month time frame. In 2020, these three CubeSats far exceeded this goal by passing the two-year milestone and adding to the list of several other long-lived ESTO CubeSats.

Each satellite's longevity has been marked by significant achievements. The Temporal Experiment for Storms and Tropical Systems – Demonstration (TEMPEST-D) and Radar in a CubeSat (RainCube) released scientifically useful data about atmospheric processes, demonstrating new ways to help bolster weather forecasts. RainCube and CubeSat Radio Frequency Interference Radiometer Technology (CubeRRT) each received U.S. patents for specific instrument technologies.

All three CubeSats achieved their core and shared purpose: to test and validate new technologies to monitor Earth from space. Here's a look back at some notable highlights.

An Orbital ATK Antares rocket launch on May 21st, 2018, transported CubeRRT, TEMPEST-D, and RainCube to the ISS. Credit: Aubrey Gemignani / NASA

CubeRRT

Passive microwave radiometry is an invaluable tool for making Earth science observations from space, but data within this spectrum has become increasingly corrupted with manmade radio frequency interference (RFI), impacting the retrievals of geophysical variables like soil-moisture and atmospheric water vapor. As the telecommunications industry advances, this problem will only get worse.
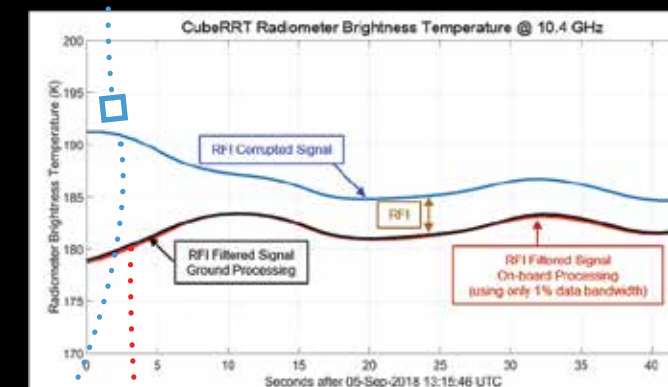
Joel Johnson, a professor of electrical engineering at The Ohio State University, developed CubeRRT to overcome this issue by detecting RFI and removing it from the data. The six-unit CubeSat mission demonstrated on-board, real-time RFI processing from space. By cleaning the data in space, Johnson's team found that on-board filtering enabled a 99% reduction in the amount of data that had to be downlinked.

CubeRRT's radiometer payload includes a broadband antenna, a broadband radio frequency front-end unit, and a digital back-end unit that performs the on-board detection, filtering, and mitigation of RFI. Despite an early failure in the radio frequency front-end unit, CubeRRT successfully demonstrated its digital back end, paving the way for future microwave instrumentation and new measurement possibilities. CubeRRT's team is proposing to integrate the technology with several future space-born missions.
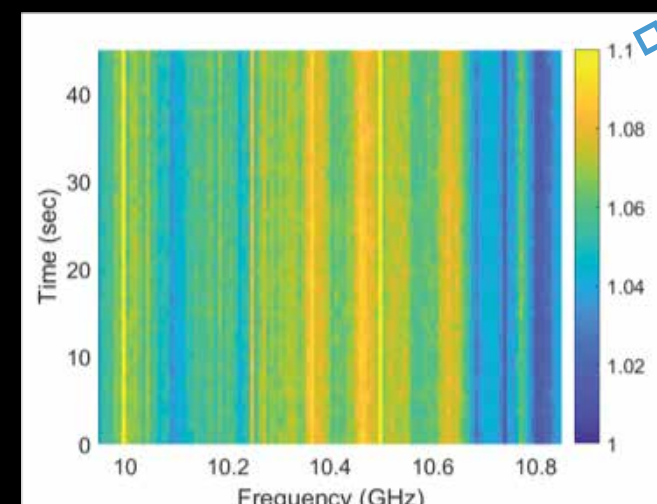
The team recently published its latest CubeRRT results in the journal, IEEE Xplore and received a patent for its ultrabroadband RF system.

A 10-minute data collection over the Pacific Ocean on September 5, 2018, produced the RFI-corrupted signal shown on the graph below.

CubeRRT Radiometer Brightness Temperature @ 10.4 GHz

RFI Corrupted Signal

RFI

RFI Filtered Signal Ground Processing

RFI Filtered Signal On-board Processing (using only 1% data bandwidth)

Seconds after 05-Sep-2018 13:15:46 UTC

The graph below shows the 128 frequency channel spectrum corrupted with RFI.

The white areas on the data below show where RFI was flagged and removed.
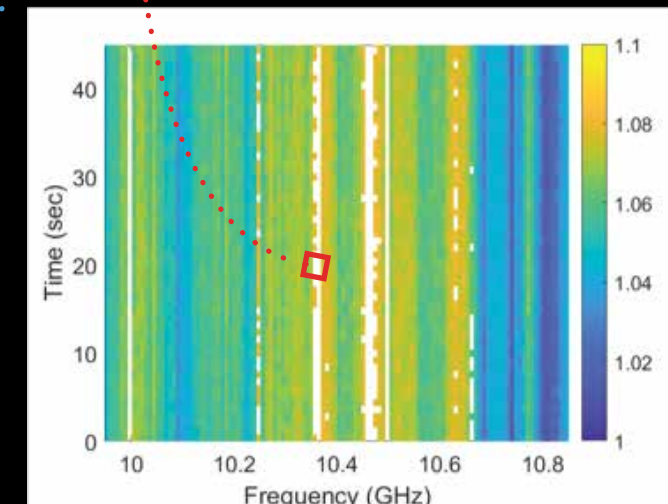
TEMPEST-D

TEMPEST-D, another six-unit CubeSat mission, demonstrated millimeter-wave radiometer measurements to remotely sense the atmosphere at a high science cost-benefit. Steven Reising, a professor of electrical engineering at Colorado State University, led TEMPEST-D's development.

This mission paves the way for affordable constellations of satellites to provide temporal observations of cloud and precipitation processes on a global scale. In the past two years, the TEMPEST-D team has demonstrated that the performance of its miniaturized sensor is indistinguishable from legacy sensors used in operational weather forecasting and science investigations.

In its extended mission, TEMPEST-D has focused on downlinking timely imagery of **high-impact weather events**, quantifying the long-term performance of the first-time-in-space low-noise amplifier technology in the sensor,

downlinking long periods of contiguous data for weather forecasting data assimilation studies, and performing unique observations not possible with operational sensors.

TEMPEST-D captured novel datasets for studying multi-angle microwave sounding of the atmosphere and tested new approaches for increasing the vertical sampling of humidity and improving measurements in the planetary boundary layer.

TEMPEST-D data are publicly available. A spare TEMPEST-D instrument is being prepared to fly on the US Air Force Space Technology Program (STP) H8 mission launching next summer to the International Space Station. The instrument will join another technology demonstration sensor, the Compact Ocean Wind Vector Radiometer (COWVR), to demonstrate low-cost sensor technologies for the Air Force and acquire simultaneous surface wind and atmospheric sounding data over the ocean.

On October 7, 2020, TEMPEST-D passed over Hurricane Delta twice as it crossed the Yucatan Peninsula and began to strengthen. The areas of red and purple indicate the strongest rain bands. The white lines indicate the edges of the area of coverage by the satellite. The colors of the storm represent the 164-GHz brightness temperatures in Kelvin.
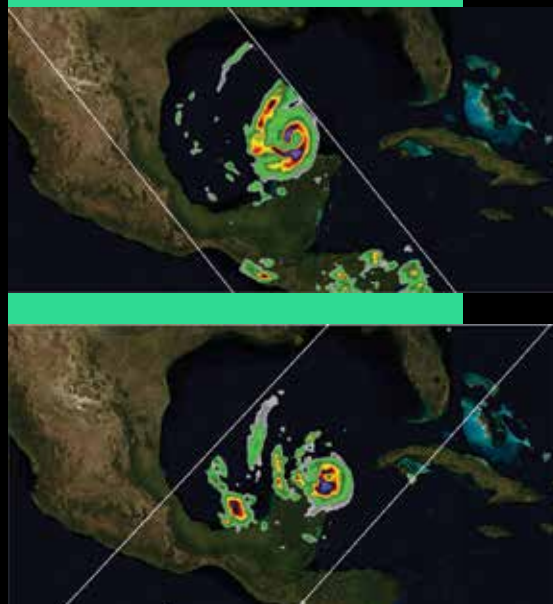
Hurricane Dorian off the coast of Puerto Rico, as seen by TEMPEST-D on Aug. 28, 2019. The colors in the image reveal the heavy rain and moisture inside the storm. The least intense areas of rainfall are shown in green and most intense are yellow and pink. Credit: NASA/JPL-Caltech/NRL-MRY

TEMPEST-D captured this first full swath image of Hurricane Florence on September 11, 2018. The colors reveal the eye of the storm, surrounded by towering, intense rain bands.

RainCube

Eva Peral, a researcher at NASA's Jet Propulsion Laboratory, led RainCube's development.

This six-unit CubeSat mission demonstrated the first radar instrument on a CubeSat. It validated a new architecture for Ka-band radars and an ultra-compact lightweight deployable Ka-band antenna in space to measure precipitation.

Over the past year, the RainCube mission has focused on better understanding the pulse compression performance of the radar instrument, improving ground models for processing the on-orbit radar instrument data, and improving the satellite's pointing capability with new algorithms.

The RainCube team is also working with Amazon Web Services' (AWS) Ground Network to perform an S-band downlink demonstration, which will help guide NASA on using these ground resources in future missions.

US patents were issued to two key elements of the RainCube radar payload – the **parabolic deployable antenna** and the offset IQ modulator. The article, "RainCube: the first ever radar measurements for a CubeSat in space," received the 2019 SPIE JARS Best Paper for Photo-Optical Instrumentation and Design.

The team continues to make progress in the planned mission operations work, to publish papers, and to present on the successes and lessons learned for the project.
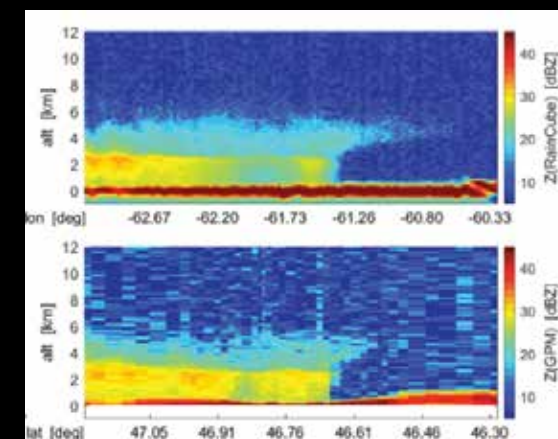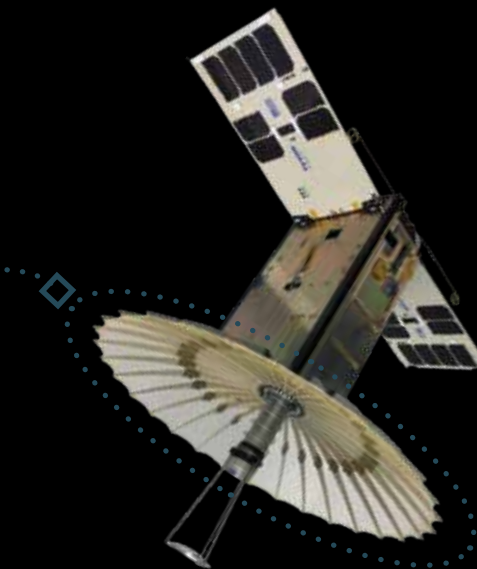
On January 25, 2019, RainCube and the Global Precipitation Measurement satellite, a joint NASA/JAXA mission, collected 'near-collocated' observations of precipitation profiles just off the coast of Canada's Prince Edward Island. In both images – RainCube (top panel) and GPM (bottom panel) – the same vertical rain cloud structures can be clearly observed from the vertical reflectivity profiling data. Because of its higher sensitivity and longer dwell time (RainCube points nadir only while the GPM radar scans across the flight track), the RainCube measurements appear to be less noisy.

In August 2020, RainCube and TEMPEST-D overflew two tropical cyclones in the Gulf of Mexico. A weakened Tropical Storm Marco can be seen on this map drenching Louisiana while the Category 4 Hurricane Laura crossed Cuba. Strong convective precipitation data from TEMPEST-D was combined with the vertical precipitation structure from RainCube providing meteorologists with a unique look inside these two storm systems.
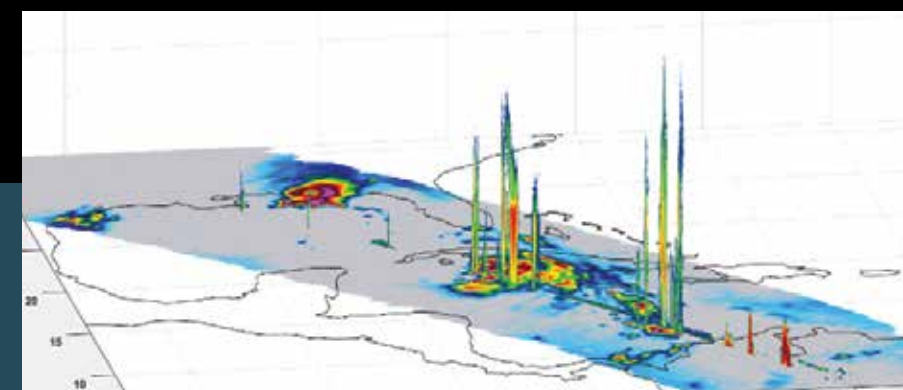
Student Participation

As with many research and development projects, students are integral to the work and success of technology development teams. Since ESTO's founding, more than 960 students from 154 institutions have worked on various ESTO-funded projects. Aided by their experiences, these students have often gone on to work in the aerospace industry and in related fields.

In FY20 alone, at least 130 students from 44 institutions were involved with active ESTO projects. Most typically, these students are pursuing under-graduate and graduate degrees, but occasionally high school students also join in on the technology development work.

The Cloud-based Analytic Framework for Precipitation Research (CAPRi) project at The University of Alabama in Huntsville is benefiting from the efforts of **Pooja Khanal**, a M.S. student in Computer Science. The CAPRi project is developing a set of server-less tools to support on demand data discovery, rendering and analysis of vast troves of precipitation data, including from the Global Precipitation Mission satellite. Pooja is working on the cloud infrastructure and computing tools that will enable researchers to access, filter, and visualize this data. Pooja says she's "fascinated by the diverse, interdisciplinary aspects of computer science and how it can be applied to everything from aerospace to genetics."

A fourth-year undergraduate at UC Santa Cruz, **Benjamin Tran** is majoring in Art and Design: Games and Playable Media, with a focus in 3D art and animation, and minoring in Computer Science. Benjamin interned with the Neural Multi-Modal Observation & Training Network for Global Coral Reef Assessment project, using his talents as an artist and visualization engineer to help develop the NeMO-Net app. Released in 2020, NeMO-Net is a single player mobile and desktop game where players help NASA classify coral reefs by painting 3D and 2D images of coral. In particular, Benjamin created the 3D underwater environment that players explore as they classify the world's coral reefs. "My goal throughout college has always been to become a game developer," said Benjamin, "and NeMO-Net helped me do just that." NeMO-Net is currently available on iOS, Mac, Windows and coming soon to Android. Visit http://nemonet.info/ for more.

Megan Ani Mirkhanian, a Civil and Environmental Engineering Master of Science candidate at the University of California, Irvine, is working as a graduate student researcher at the NASA Jet Propulsion Laboratory for the GeoGateway QUAKES-A project. GeoGateway is a data product search and analysis gateway for scientific discovery, field use, and disaster response. Megan is involved in community outreach and engagement for GeoGateway and is helping to develop a user guide as well as tutorial videos about the datasets and models hosted on GeoGateway. Her work will help novice users – students, first responders, and scientists – access the system as they research, prepare for, and work to mitigate natural disasters.
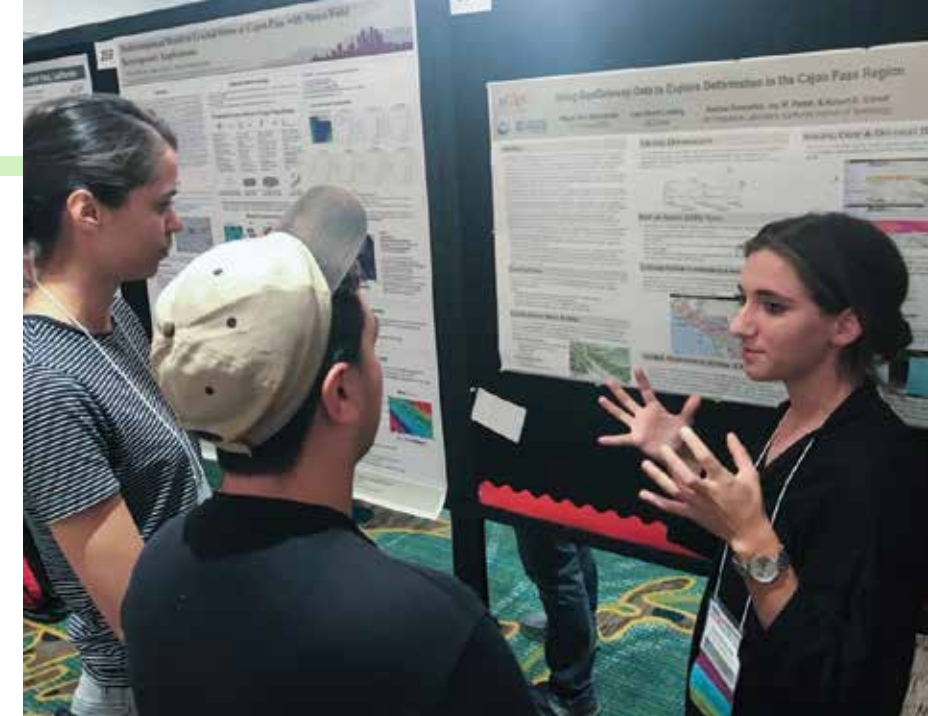
Benjamin Nold, is a Ph.D. student in Electrical Engineering at Purdue University where he works on microwave instrument design, microwave instrument software signal simulators, and data processing methods. Benjamin is supporting the SigNals of Opportunity: P-band Investigation (SNoOPI), a CubeSat mission that aims to validate a new, promising technique for soil moisture and snow measurements from space. "By using signals in the P-Band range, we expect to be able to demonstrate a sensitivity to soil moisture to beyond a meter depth into soil and a high sensitivity to snow water equivalence," said Benjamin. "For me this is exciting because I get to play a small role advancing scientific knowledge of our planet." During summers, Benjamin is also a Pathways Intern at NASA Goddard Space Flight Center where he is working on a miniaturized, multi-signal GNSS receiver.

A Ph.D. student in Electrical Engineering at the University of Southern California, **Max Lien** was awarded a NASA Space Technology Graduate Research Opportunities (NSTGRO) fellowship in 2020 and began working with ESTO principal investigator Sarath Gunapala at the Jet Propulsion Laboratory . Max is assisting with the development and testing of mid-wave infrared black phosphorus detectors, which could eventually be employed to measure Earth's surface temperature among other uses. His interest in optical systems began during undergraduate studies in electrical engineering at the University of Wisconsin–Madison, where he was involved in a project that used drone-based hyperspectral sensors to track ecological changes. Max also studies classical piano at the USC Thornton School of Music.